# *Impurities Diffusion Across Private Flux Region Toward X-point During ITER Elms*

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# I. ITER Plasma Parameters at Normal Operation and ELMs

**Used parameters:**

### Normal operation - Physics Phase

- $R = 6$ m, $\quad a=2$ m, $\quad k=2$, $\quad \delta=0.24$

- $B_\theta=5$ T, $\quad I_\theta=22$ MA, $\quad Z_{eff}\approx 1$ (in project- $Z_{eff}\approx 1.5$),

- $n_e=10^{14}$ cm$^{-3}$, $\quad T_e=T_i=T_0=10$-$20$ keV,

- $Q_{thermal} = Q_0 = 1$-$2$ GJ,

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# ITER ELMs

- **The ELM instability results from an overlap of many MHD modes.**

- **There are many types of ELMs varying from machine to machine (up to 5 in the NSTX).**

- **Plasma energy losses during ELMs varies up to (10-30)%.**

- **May be only pedestal plasma is expelled during ELMs: if MHD instability propagates into the hot core (inside the thermal barrier) it results in a disruption.**

- **Thus, energy, $Q_{ELM}$, and particles, $N_{ELM}$, expelled during ELM with magnitude, $\xi$, is assumed as loss of outer regions containing the given $Q_{ELM}$ and $N_{ELM}$.**

# Modeling Stages in HEIGHTS



**Core Plasma** → **SOL Plasma** → **Divertor** → **PFC Response**

**Core Plasma:**
- Model for Energy Transport
- Temperature Distribution
- Particle Distribution
- Energy Profile
- Origin of ELMs

**SOL Plasma:**
- Collisionless Plasma
- Fokker-Planck Solution
- Particle Distribution
- Spatial Profile

**Divertor:**
- Particle Deposition
- Hydrodynamics Evolution
- Plasma/vapor Interaction
- Radiation Hydrodynamics

**PFC Response:**
- Cloud Formation
- Vapor Expansion Dynamics
- Erosion Mechanisms
- Erosion Lifetime

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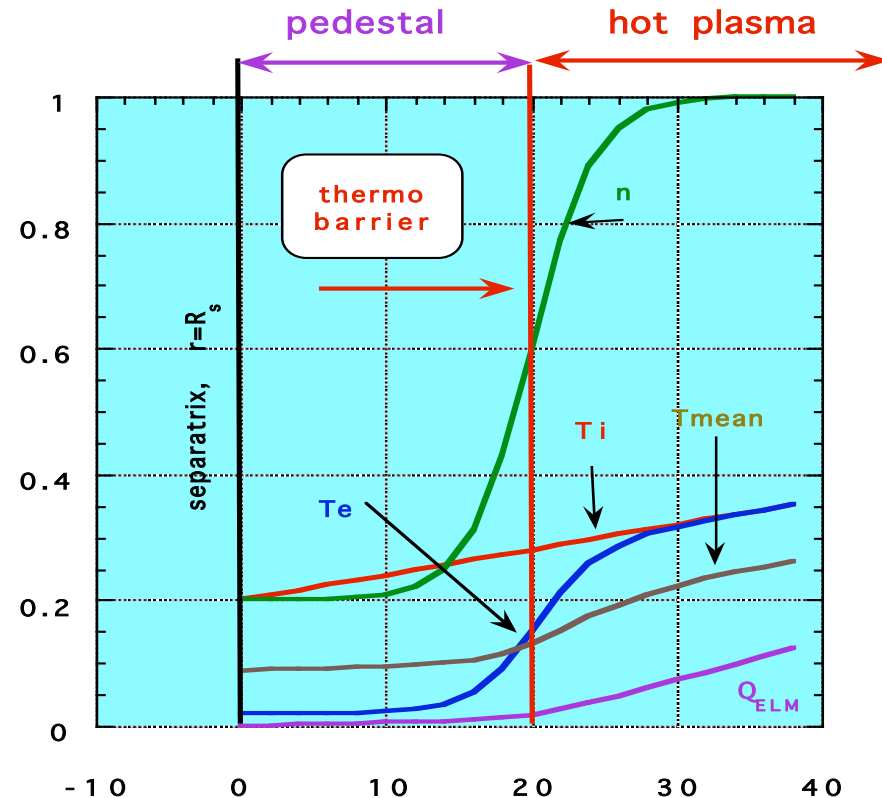December 5-7, 2004

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# What part of core plasma comes to SOL during ELM?

- **The energy, $Q_{ELM}$, and particles, $N_{ELM}$, expelled out during ELM with magnitude, $\xi$, is assumed as loss of outer ring containing the given $Q_{ELM}$ and NELM**

Space distribution at the tokamak edge

pedestal        hot plasma

thermo barrier

n

Ti      Tmean

Te

separatrix,  r=R$_s$

$Q_{ELM}$

1    0.8    0.6    0.4    0.2    0

-10    0    10    20    30    40

# II. Cloud of mixture of coming DT plasma and vaporized carbon plasma

## The main consequence of ELMs development:

- plasma coming from the pedestal has low temperature (T≈1 keV),
- thus cloud above the divertor plate surface consists mostly from DT plasma
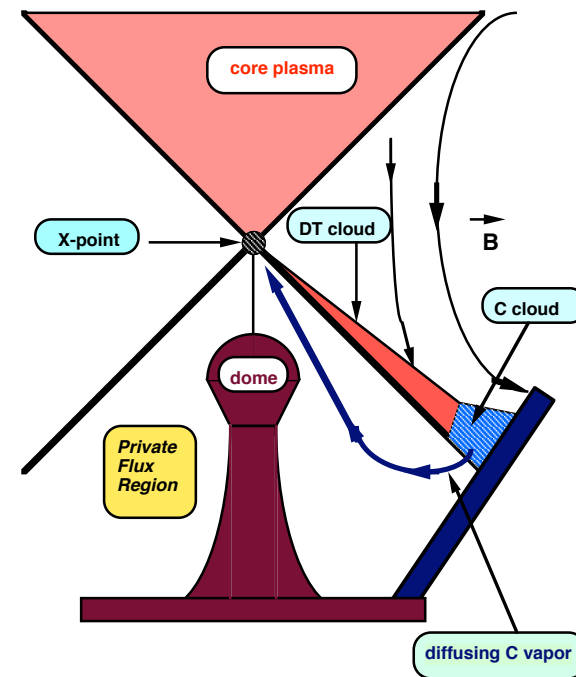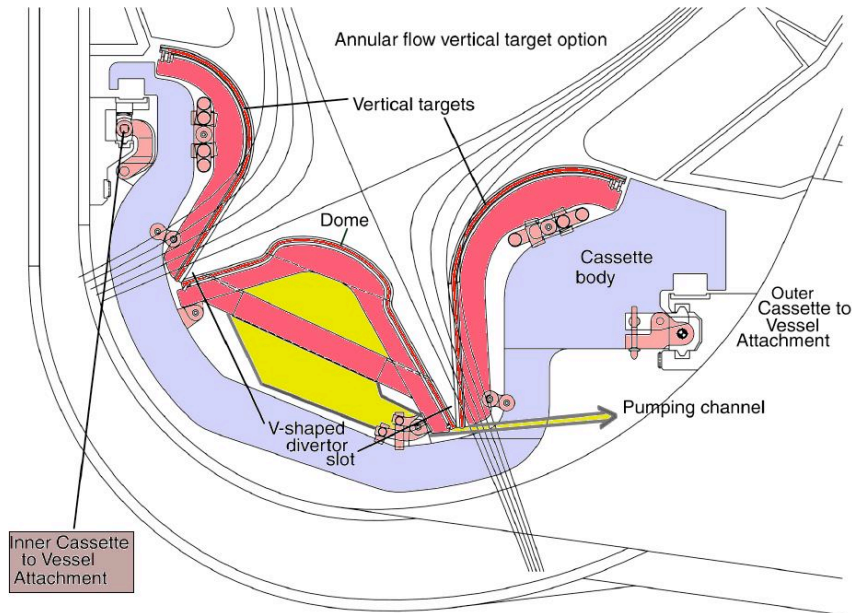- This DT cloud is kept the vaporized carbon plasma nearby the surface
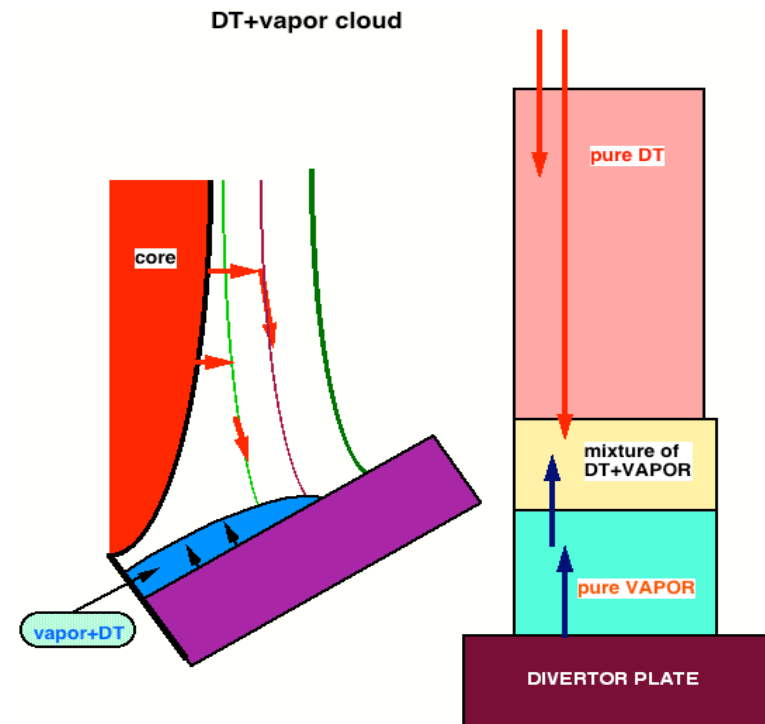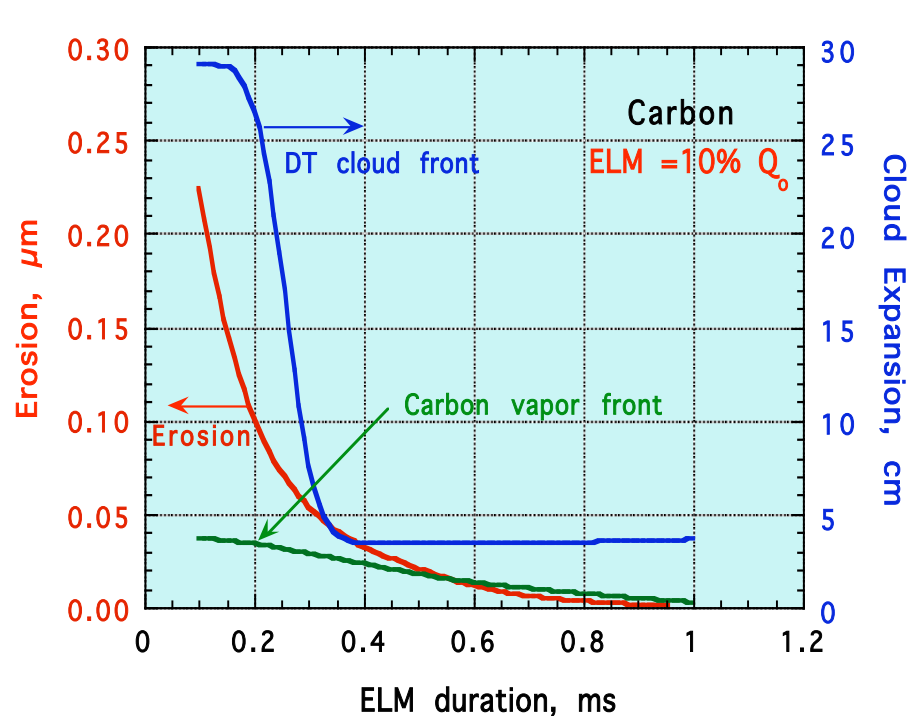
# Beryllium Erosion & Expansion

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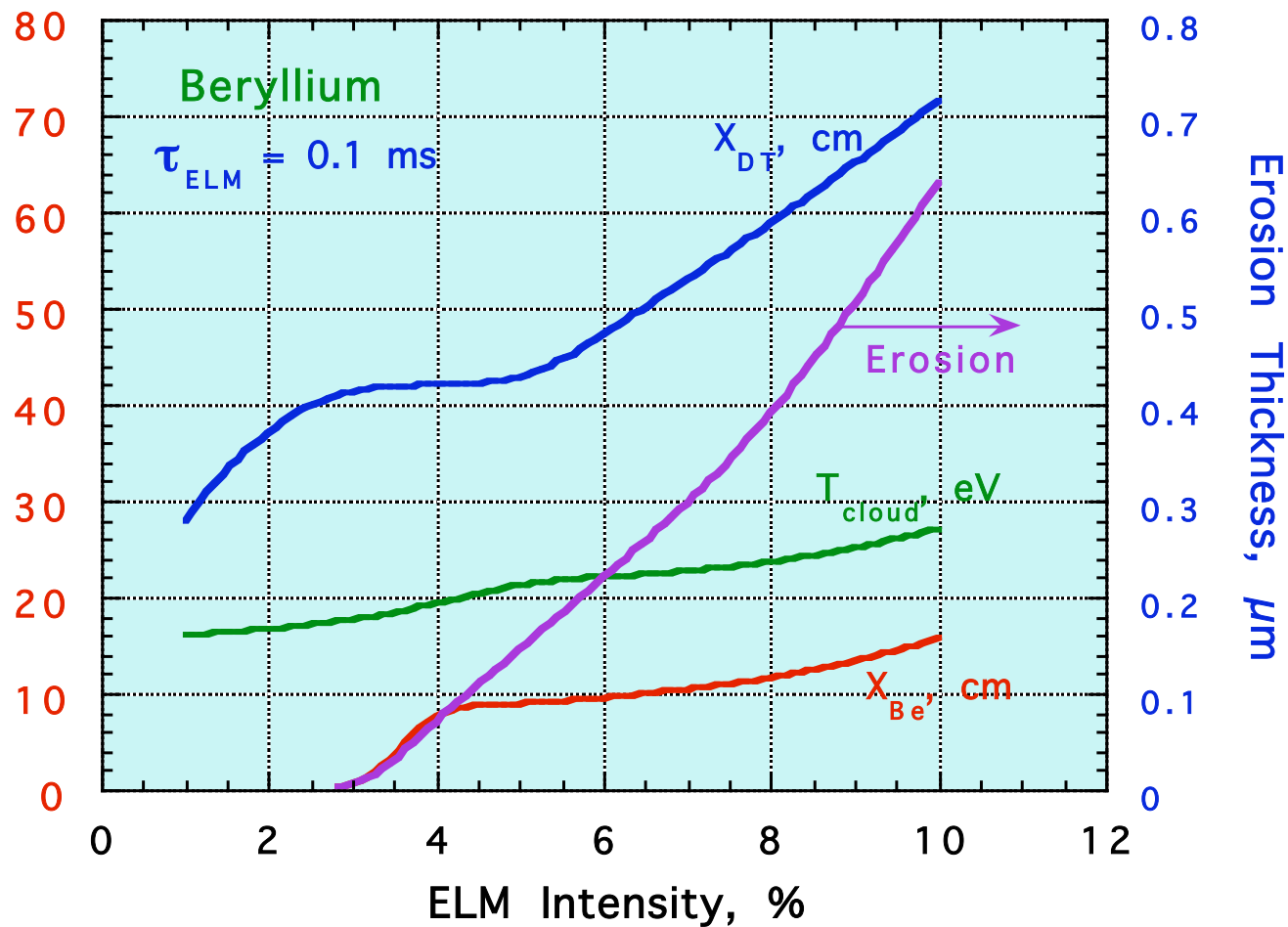
## Assumption:

- **Carbon plasma is lost due to diffusion across the Separatrix into the Private Flux Region (PFR)**

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# Impurity Transport

- Diffused carbon plasma is well magnetized and its dynamic can be described by the Hall approximation assuming quasistationary motion with velocity, $V_\perp$. Substituting $V_\perp$ in mass conservation equation one can obtain nonlinear diffusion equation.

- Mass conservation law:

$$\frac{\partial n}{\partial t} + div\left(n\vec{V}_\perp\right) = 0, \qquad V_\perp = -\frac{4\pi D_\perp}{B^2}\nabla_\perp P, \qquad D_\perp = \frac{c^2}{4\pi\sigma_\perp}$$

$$\frac{\partial n}{\partial t} = div\left(n\chi\vec{\nabla}n\right) \quad - \quad dimensionless\ form$$
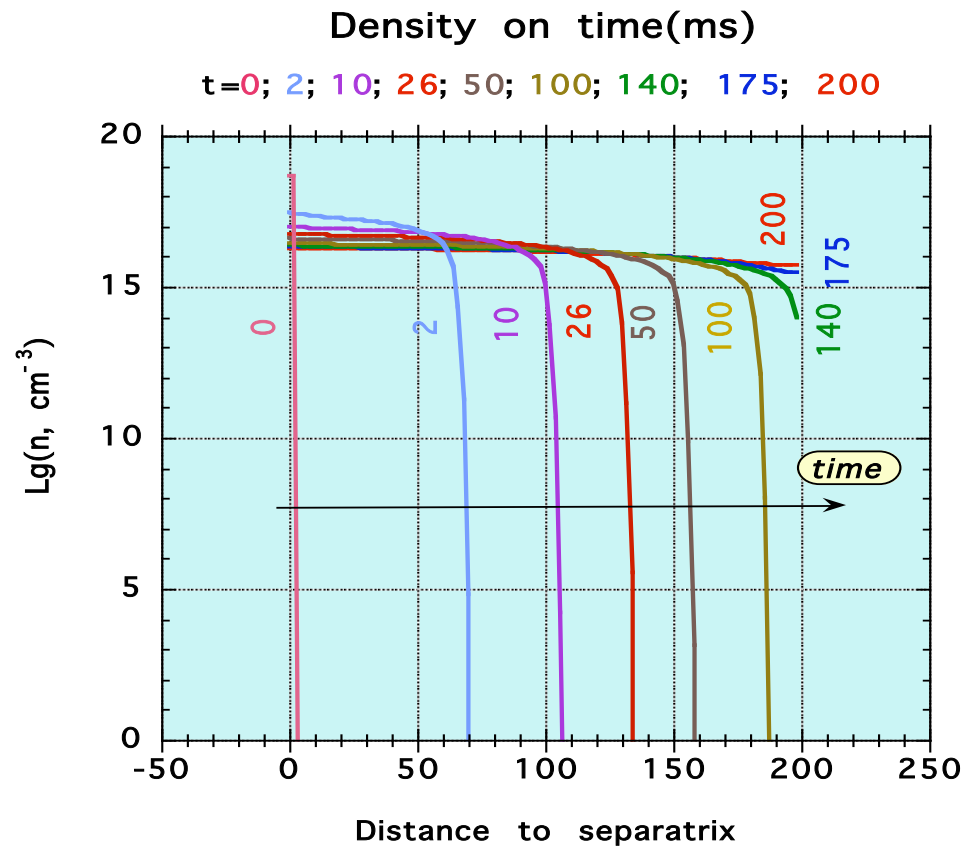
where coefficient, $\chi$, depends on temperature.

Energy conservation law:

$$\frac{d\varepsilon}{dt} + Pdiv\vec{V} = -div\left(k\vec{\nabla}T\right) + Q_{joule} + Q_{rad}$$

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# *Density at the PFR*

## Propagation of carbon plasma in the PFR



Density on time(ms)

t=0; 2; 10; 26; 50; 100; 140; 175; 200

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- **Carbon plasma propagates with sharp front because effective diffusion coefficient depends on density**
  - **diffusion is nonlinear**

**Propagation of carbon plasma front with n=$10^{14}$ cm$^{-3}$**

Density front, $X_{14}$, with n=$10^{14}$ cm$^{-3}$



X-point

$X_{14}$

Strike-point

t, ms
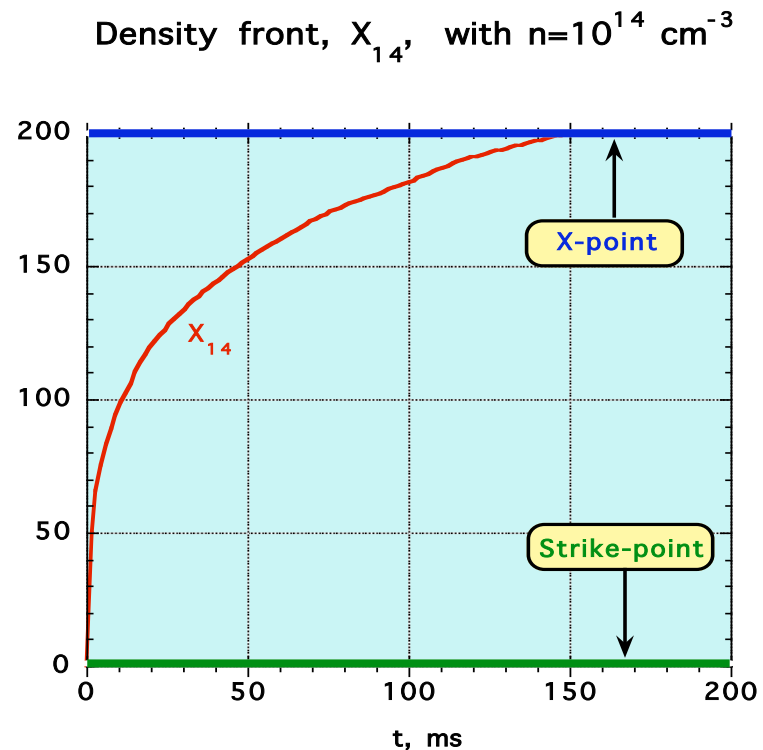
# *IV. Summary*

1. The plasma cloud during ELMs consists mostly of DT plasma.

2. This DT plasma with high temperature ($T_{DT}$ = 40-60 eV) confine carbon plasma below with lower temperature ($T_C$=10-20 eV).

3. The carbon plasma can diffuse across Separatrix into the private flux region and be the main mechanism of the carbon vapor leakage.

4. Carbon impurities reaches the X-point in time of 100 ms much longer than ELMs time of 0.1-1 ms and could penetrate into core plasma.

5. Contamination of core plasma is governed by pumping and absorption of vapor plasma by components in PFR.

6. Need more detail analysis for the interaction of eroded material with PFR materials, pumping, and bulk plasma.